Type Ia Supernova Cosmology: Taming Systematic Uncertainties

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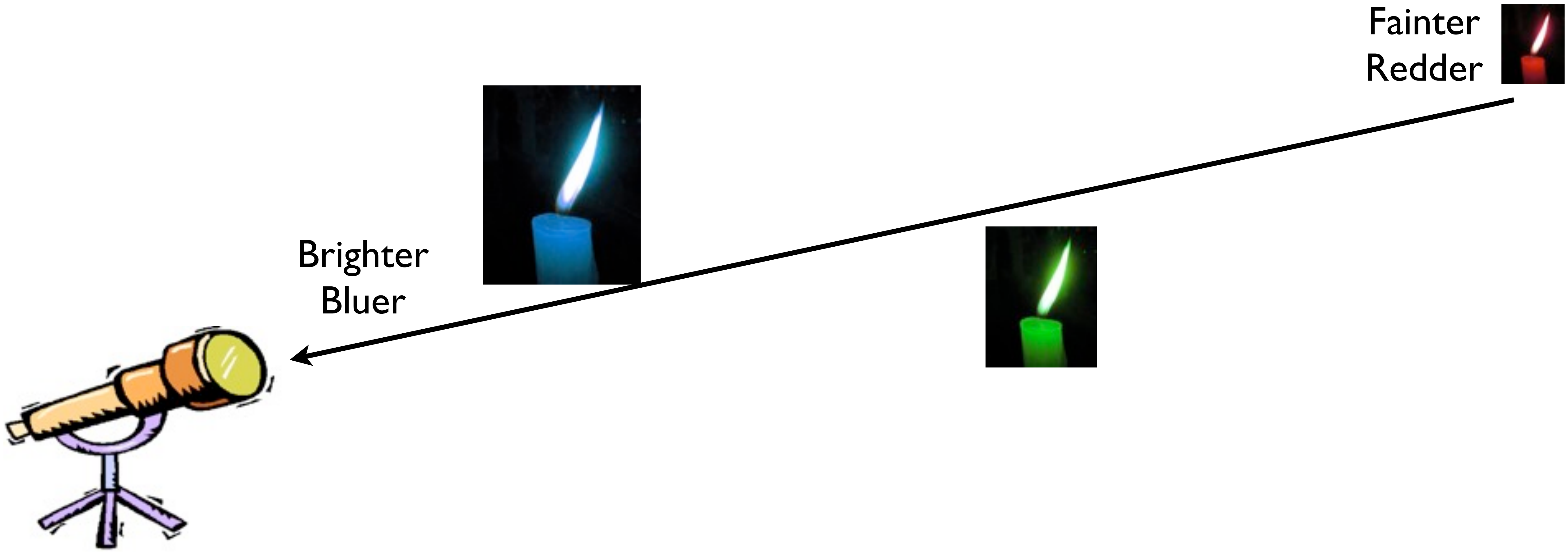
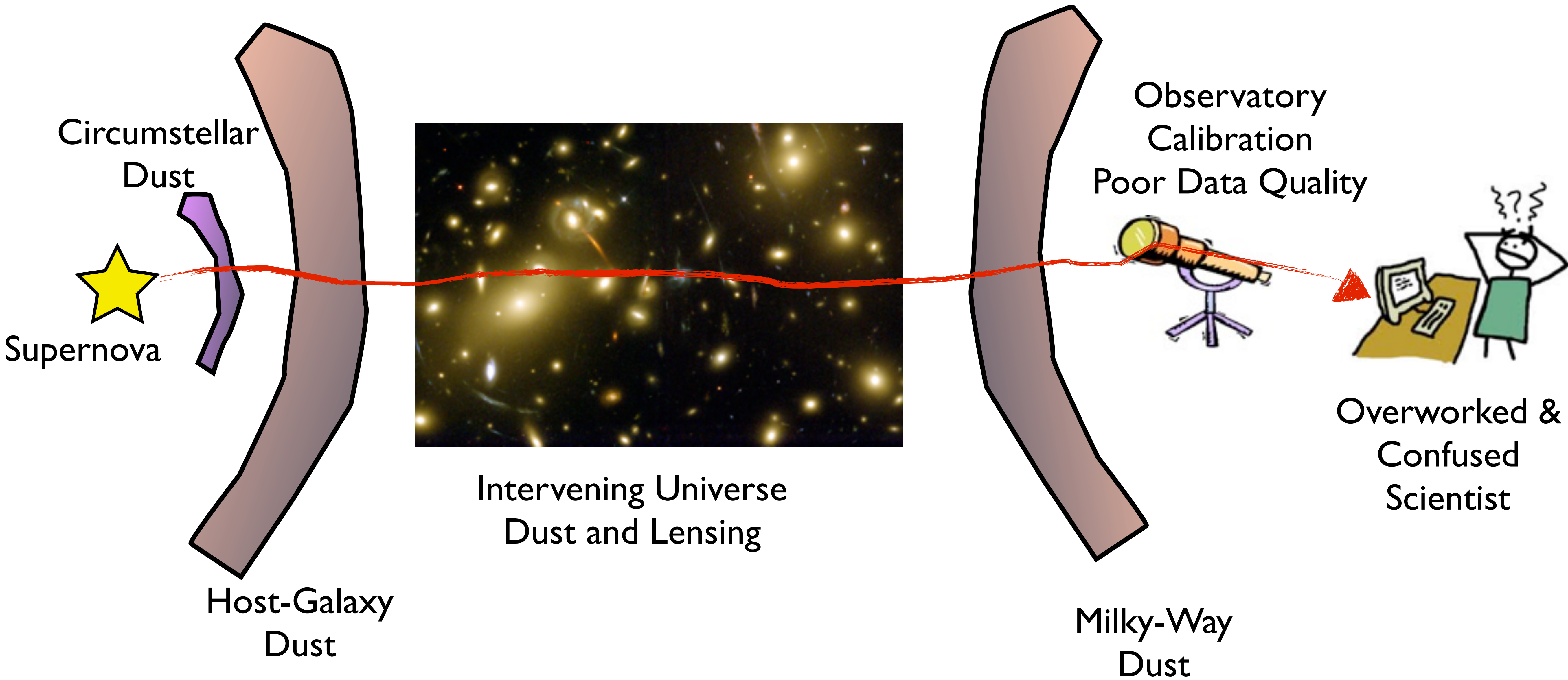
Standard Candles To Cosmology: Measurement



- For a set of standard candles of luminosity L
  - Measure flux f
  - Measure redshift z

Sources of Systematic Uncertainty



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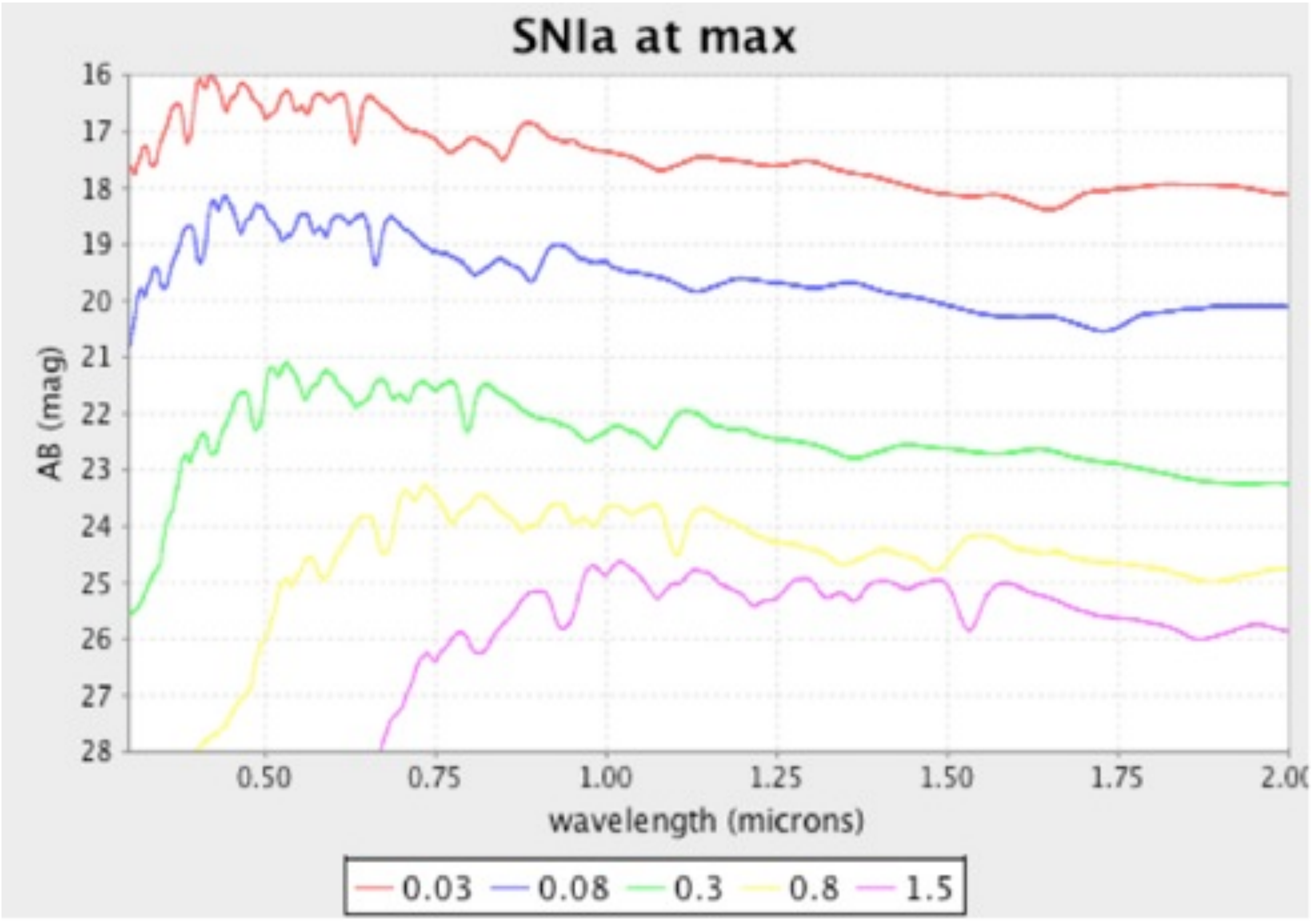

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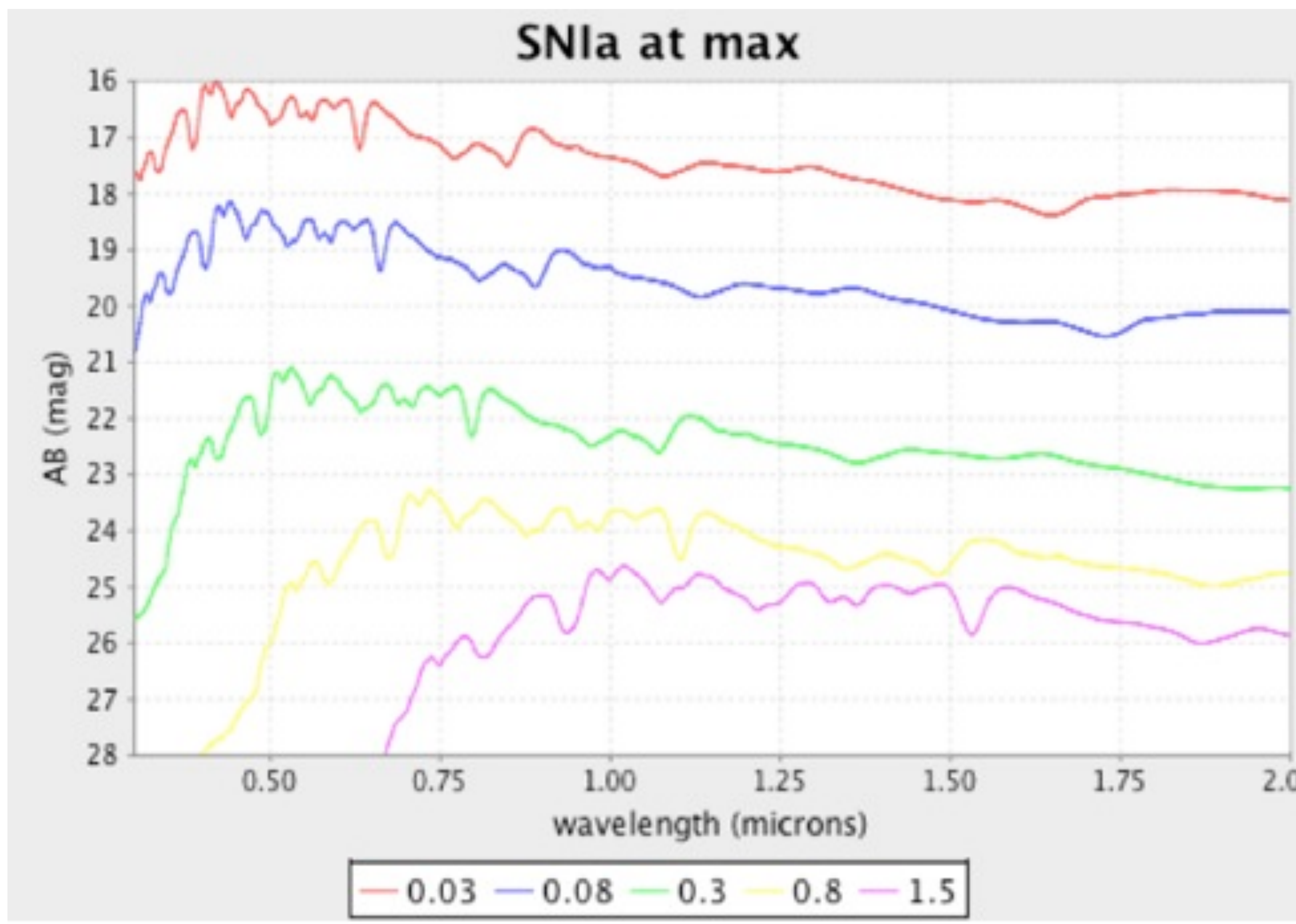
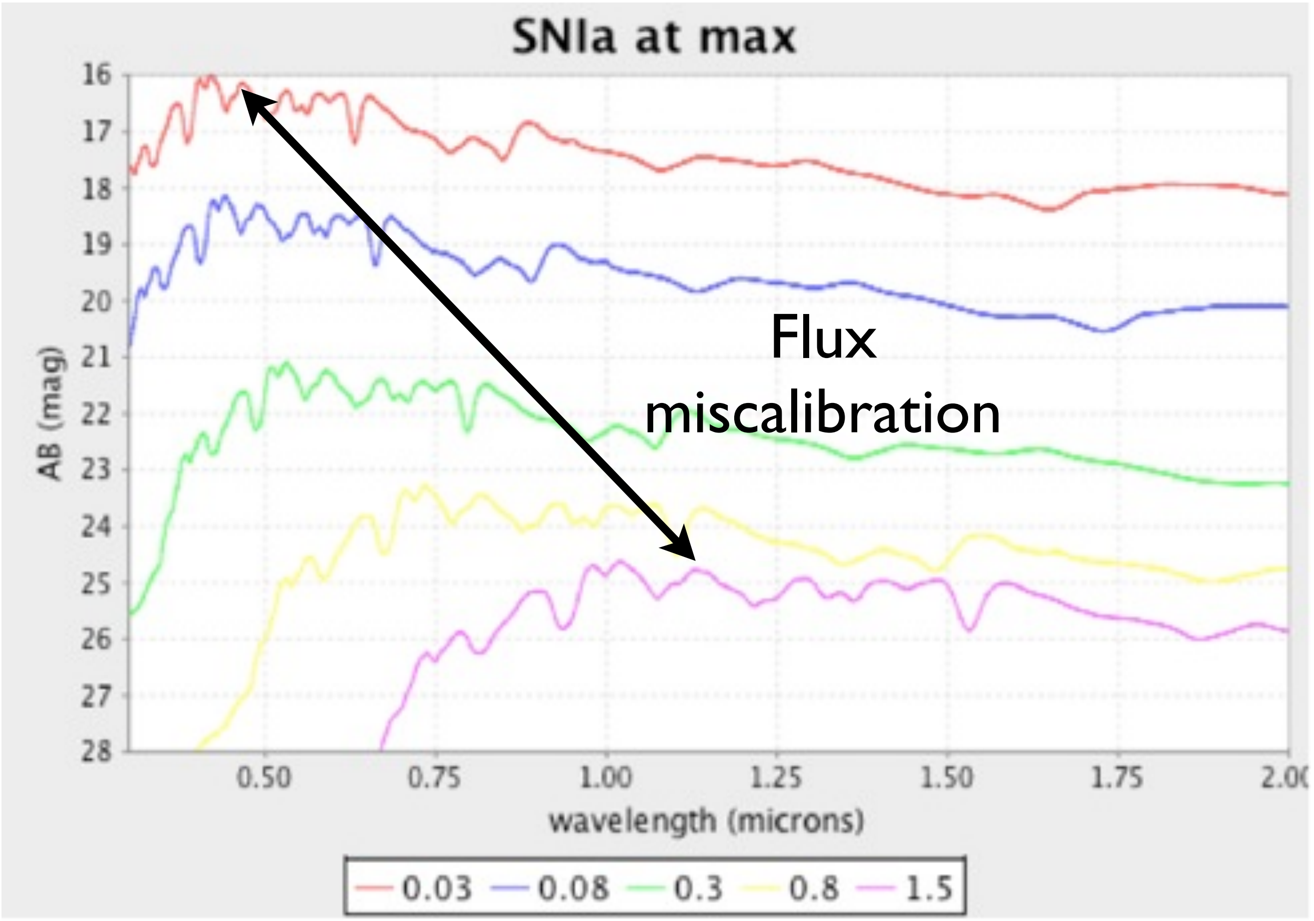


SNe at low- and high-z are different

Sources of Systematic Uncertainty



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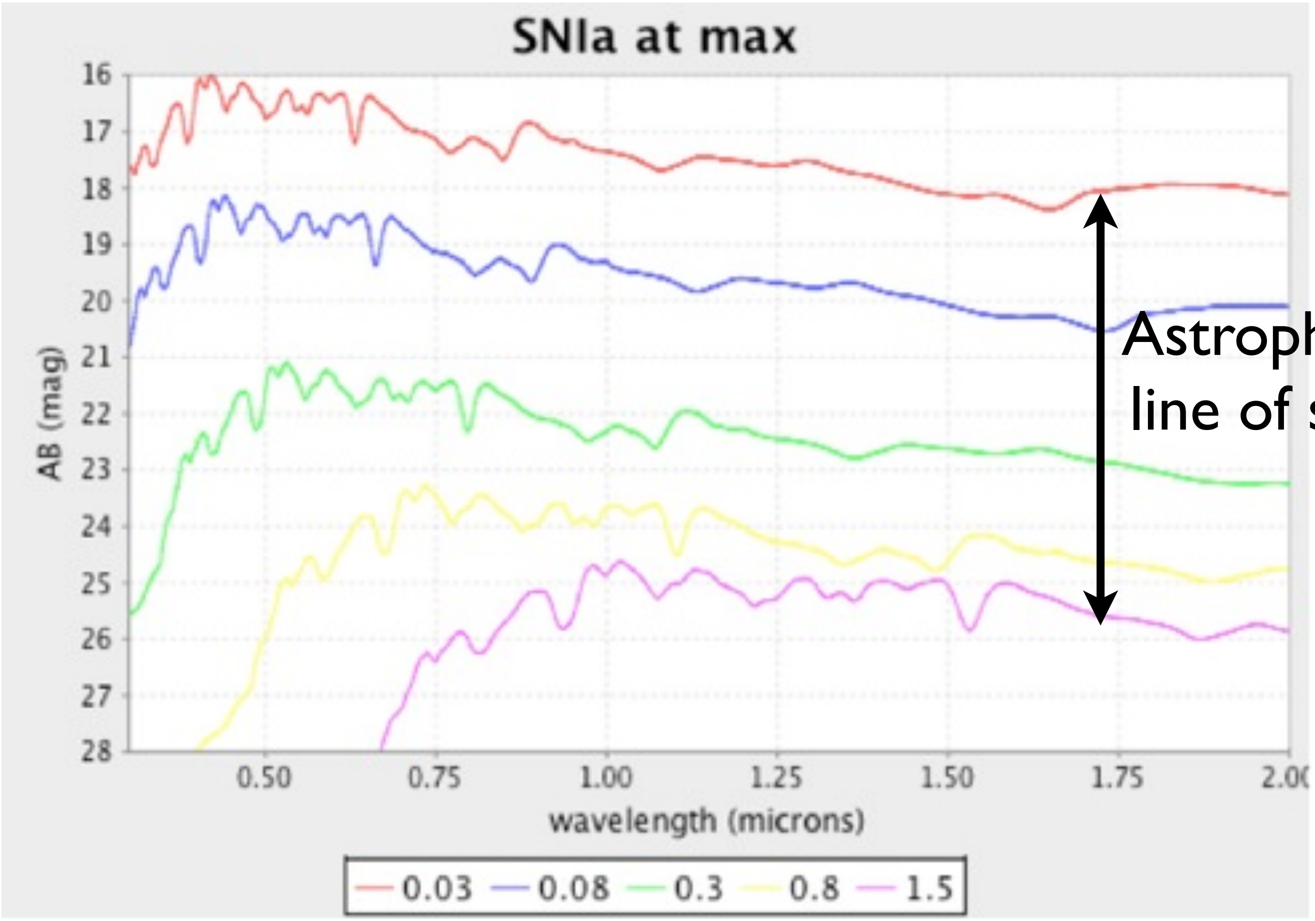
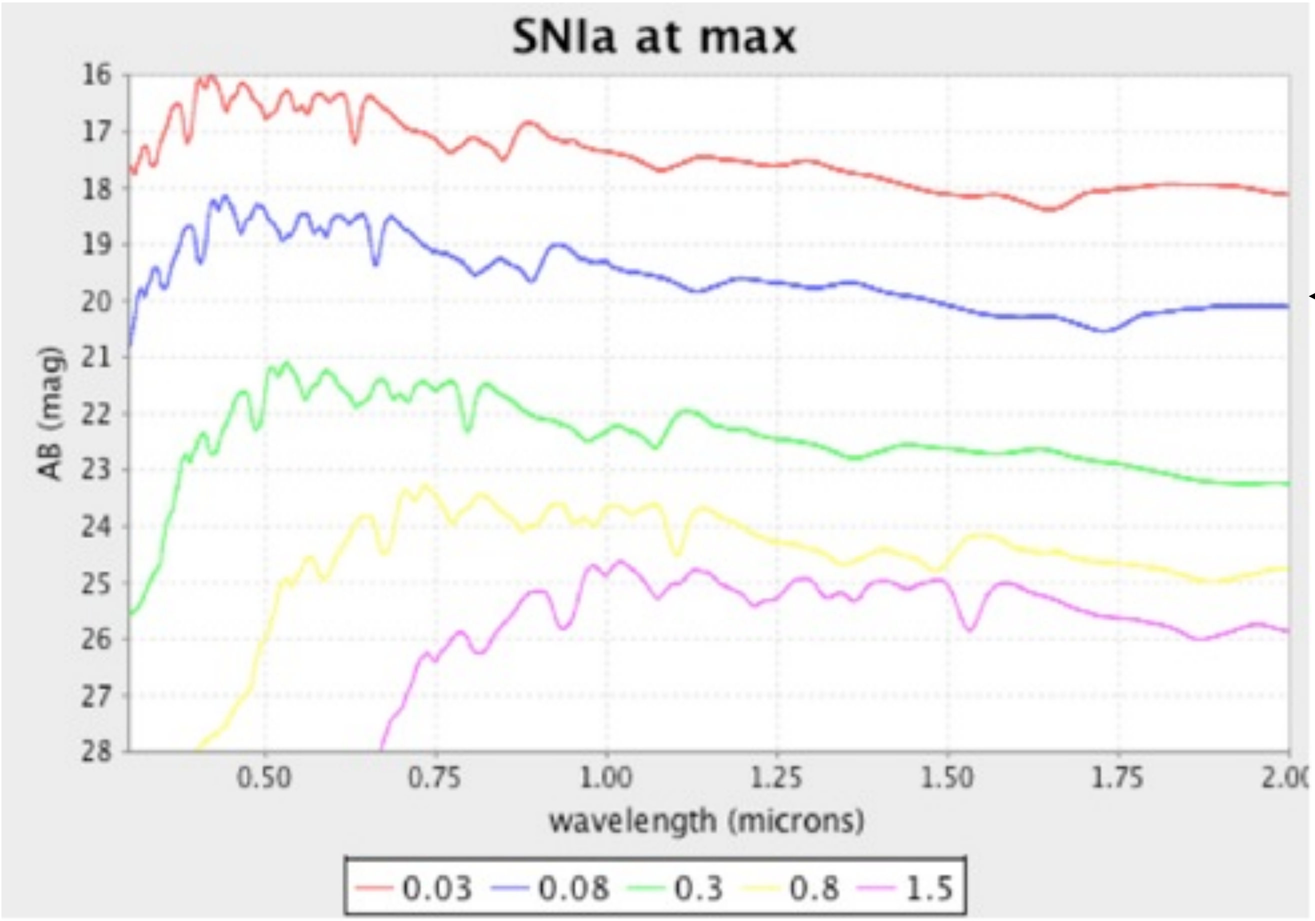


Astrophysics in the line of sight affects flux

Sources of Systematic Uncertainty



Inaccurate
SN flux model

Systematic Uncertainties in Error Budget

Table 5
Effect on constant w error bars and area of the 95% $w_0 - w_a$ confidence contour (inverse DETF FoM) for each type of systematic error, when SN Ia constraints are combined with constraints from CMB, H_0, and BAO.

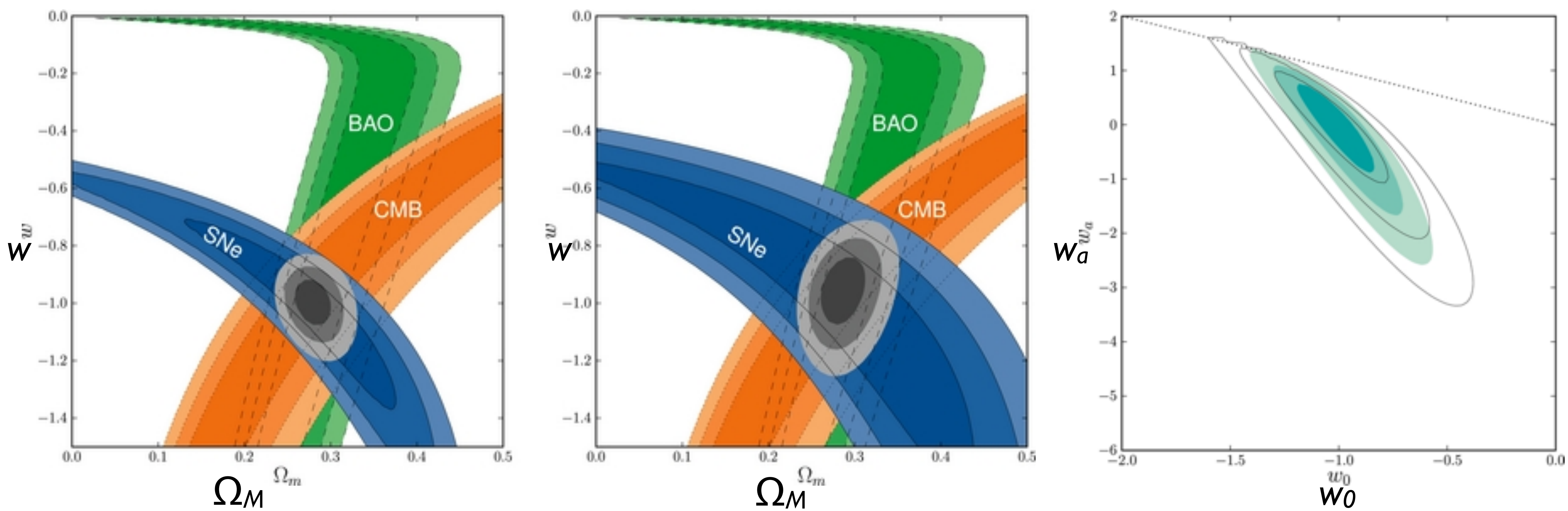
	Source	Error on Constant w	Inverse DETF FoM
	Vega	0.033	0.19
	All Instrument Calibration	0.030	0.18
Calibration	(ACS Zeropoints)	0.003	0.01
	(ACS Filter Shift)	0.007	0.04
	(NICMOS Zeropoints)	0.007	¡0.01
Data Quality	Malmquist Bias	0.020	0.07
SN Ignorance Circumstallar and Host Dust	Color Correction	0.020	0.07
SN Ignorance	Mass Correction	0.016	0.08
Data Quality	Contamination	0.016	0.05
Intergalactic Astrophysics	Intergalactic Extinction	0.013	0.03
Milky Way	Galactic Extinction Normalization	0.010	0.01
SN Ignorance	Rest-Frame U-Band Calibration	0.009	¡0.01
	Lightcurve Shape	0.006	¡0.01
	Quadrature Sum of Errors/ Sum of Area (not used)	*0.061*	*0.68*
	Summed in Covariance Matrix	0.048	0.42

Suzuki et al. (2011)

Current Results Limited By Systematic Uncertainties

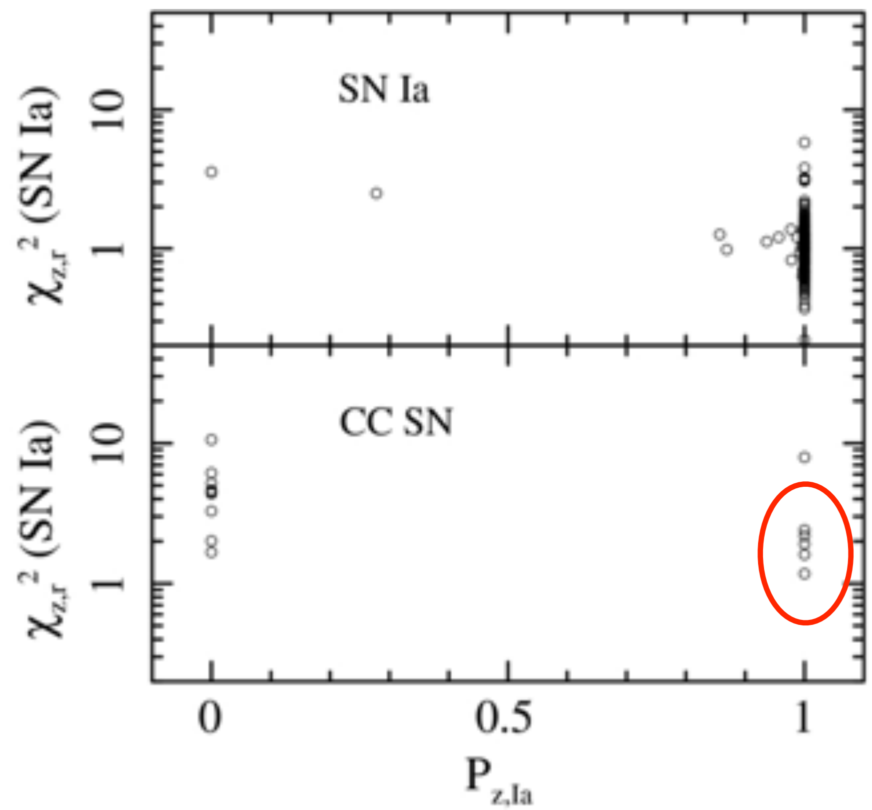
- Dark energy parameter contours without and with systematic uncertainty
- Contours without systematics much smaller
- Systematic uncertainties dominant

Suzuki et al. (2011)



A "New" Systematic": Photometry-only Supernova Cosmology

- DES and LSST projections include SNe that have not been classified spectroscopically
- Current-generation photometric classifiers tag non-SN Ia as SN Ia even with a redshift prior



Sako et al. (2011)

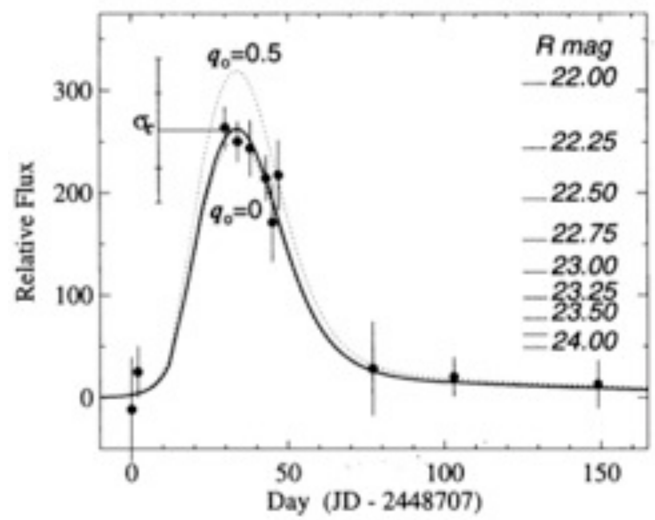
- False positives bias measurement of expansion history

Approach to Lower Systematic Uncertainties

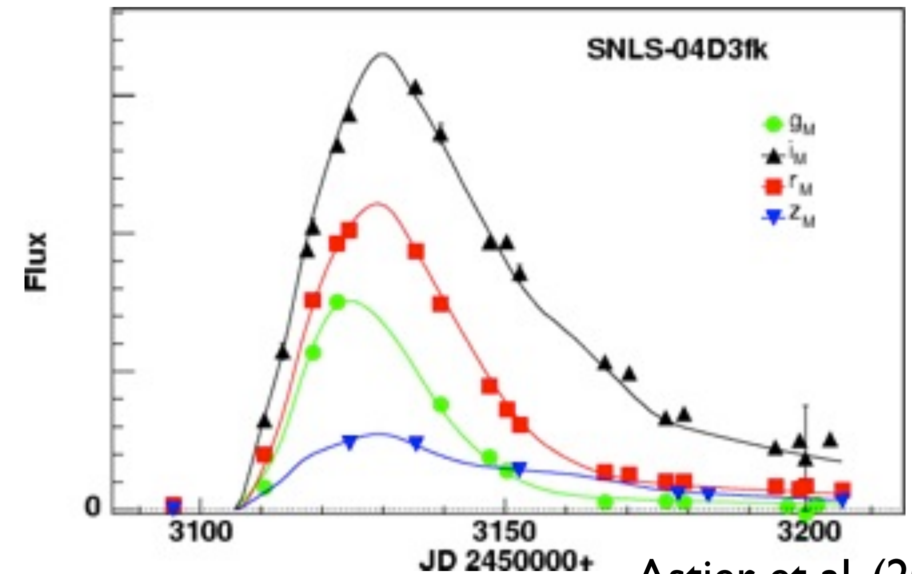
- Better data to get a more complete view of each supernova
  - New windows to exploit: Spectrophotometry, near-infrared
- Improve models used to determine SN Ia luminosity
  - Requires intensive study of nearby SNe
- Improve flux calibration
- Census of backgrounds transients to quantify bias from photometric classification

Modern SN Data Set: Reduces Standardization Systematics

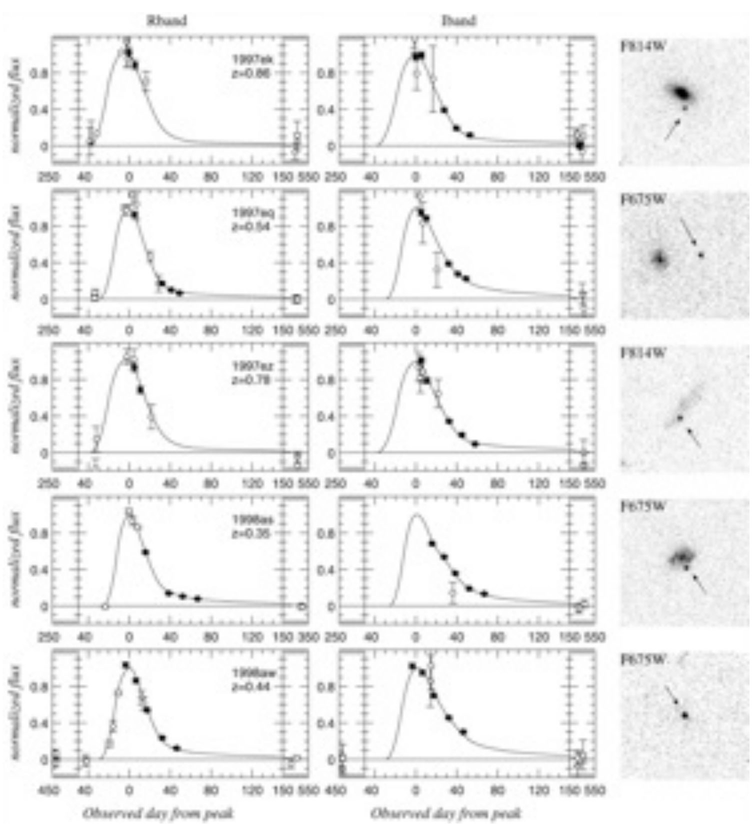
- With better quality data comes better quality distances
- Supersedes previous SN data

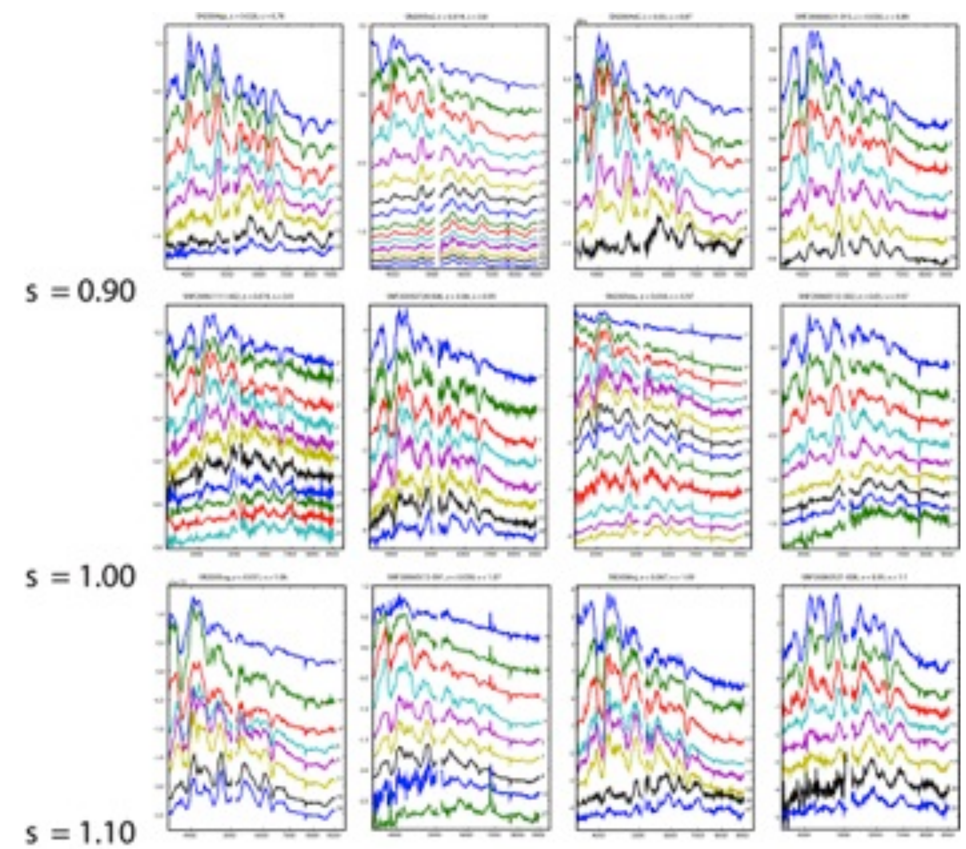


Perlmutter et al. (1995)



Astier et al. (2006)

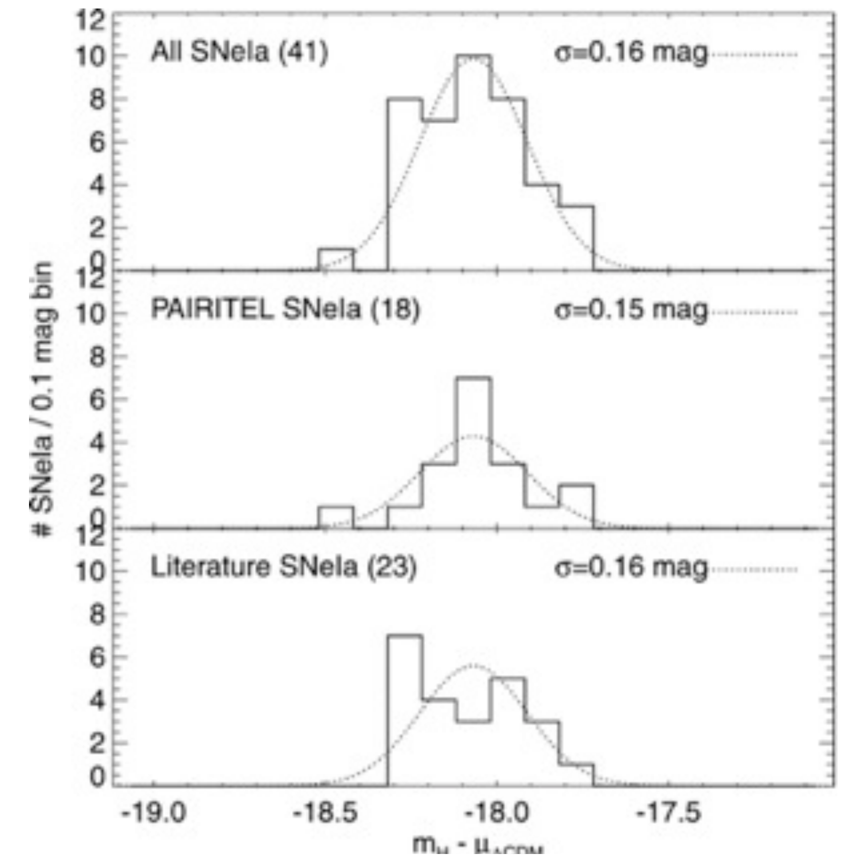

Knop et al. (2003)



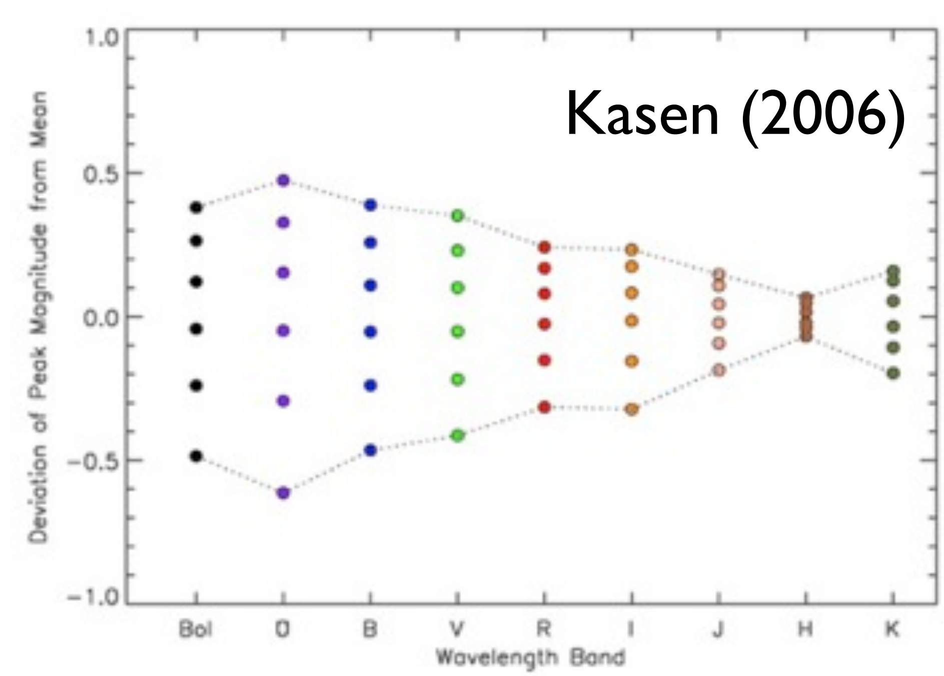
Aldering et al. (2010)

Near-Infrared: Another Window Reduces Dust and Standardization Systematics

Wood-Vasey et al. (2008)



- SNe are observed to have ~0.15 absolute magnitude dispersion in the NIR with no light curve or dust corrections
- Less susceptible to dust extinction
- Small dispersion in the NIR also seen in SN explosion models



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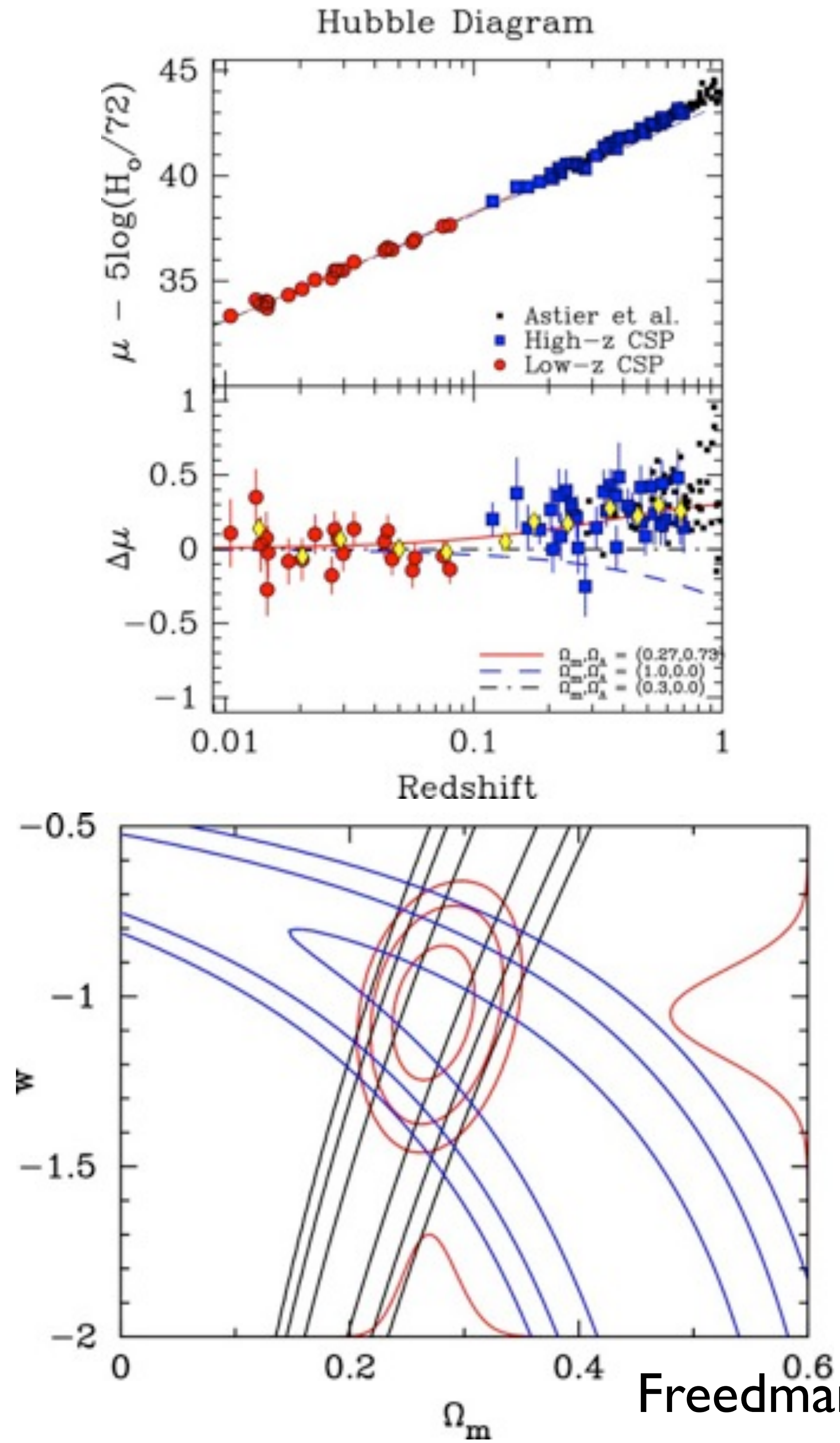
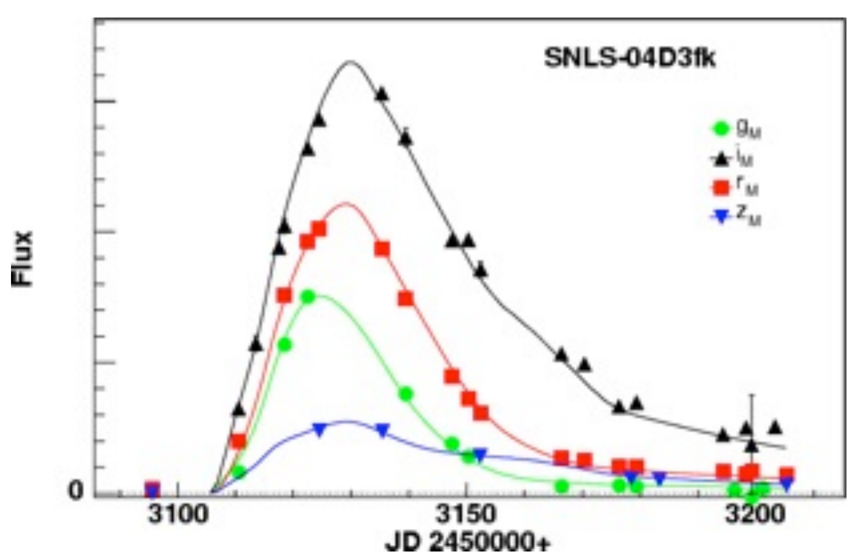


Freedman (2009)

Uncertainty in SN Model

- Supernova distances determined from fits of multi-band light curves
  - Depends on magnitude at peak brightness, light-curve decline rate , and color



Luminosity

Uncertainty in SN Model

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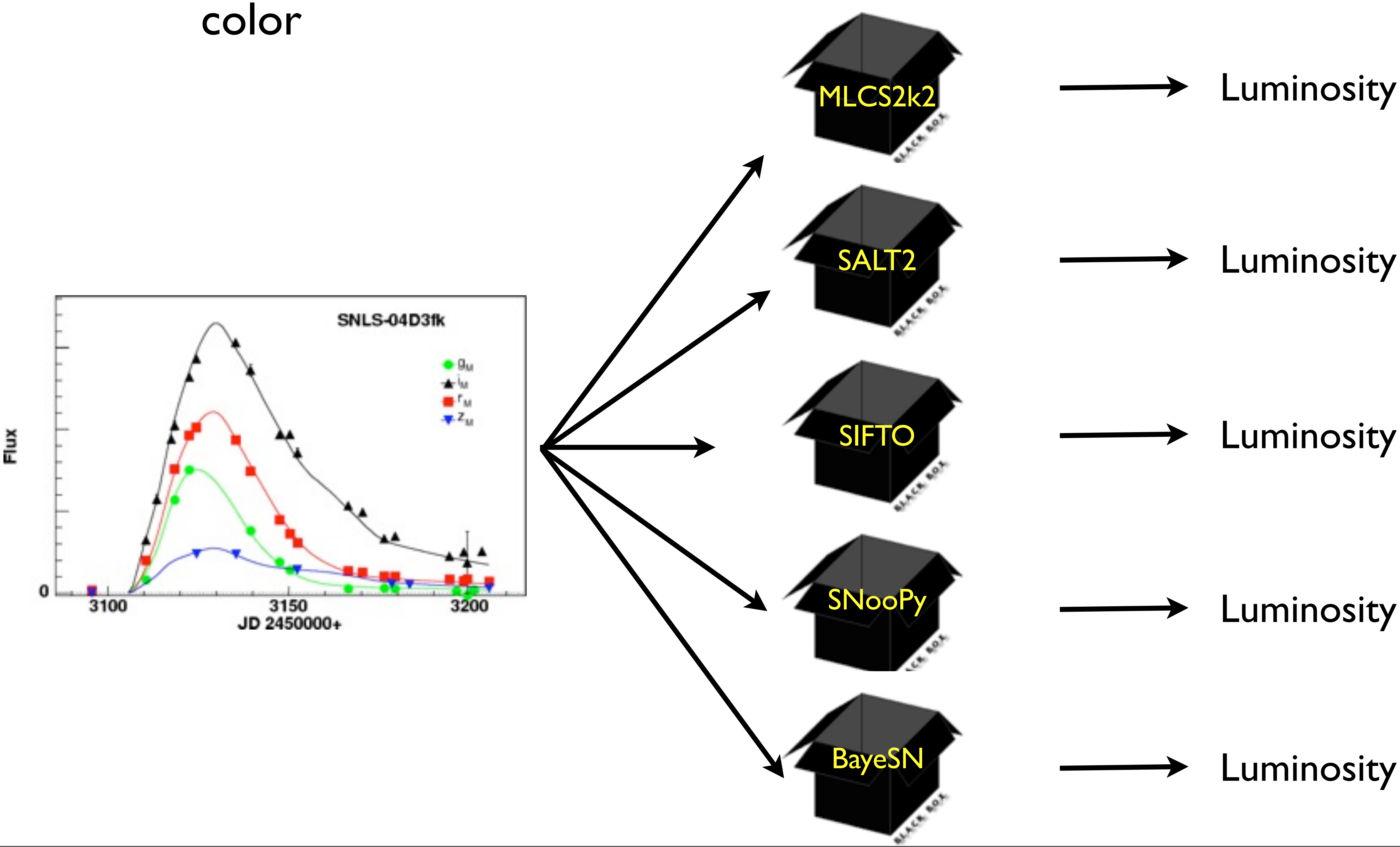
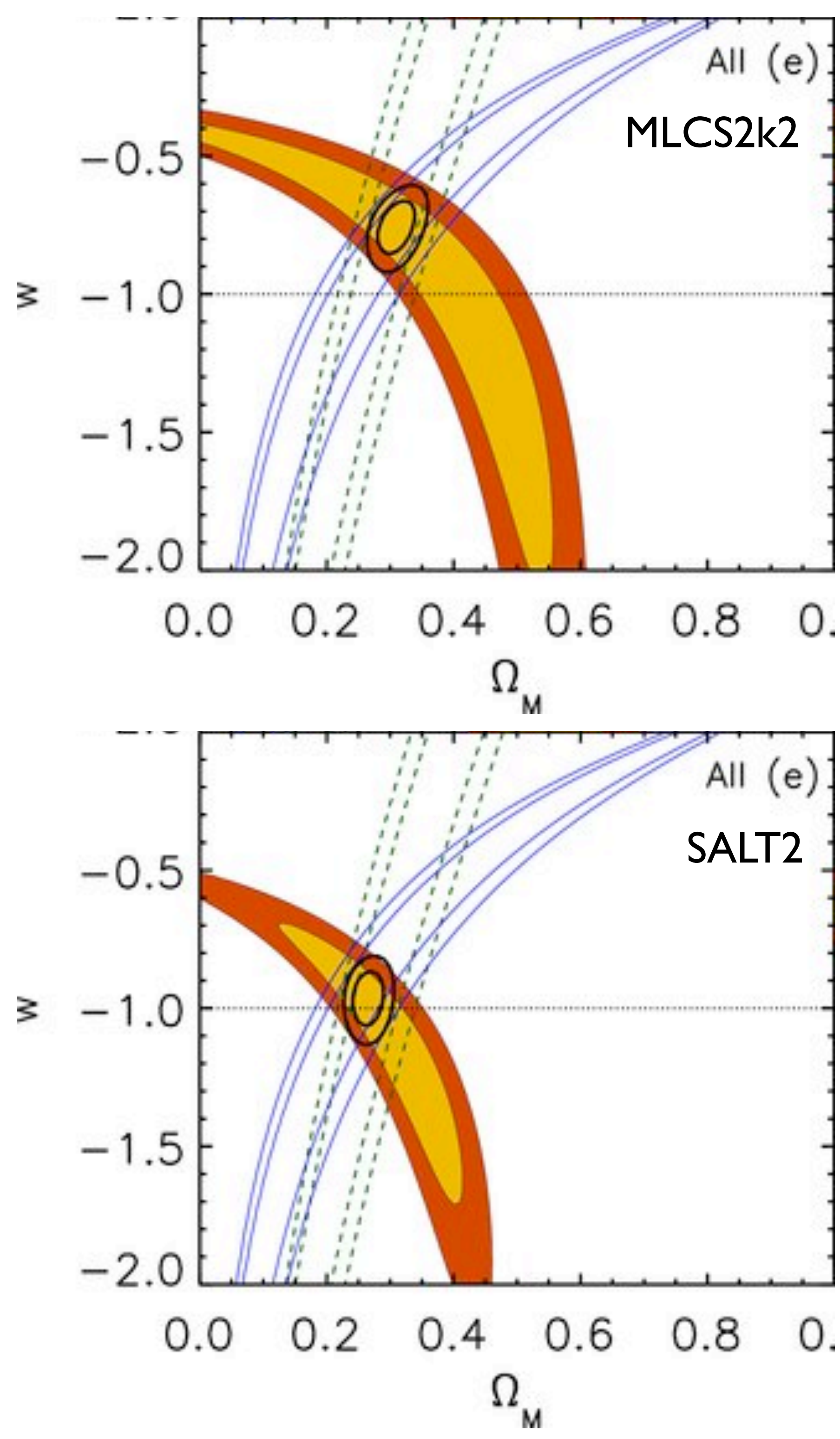


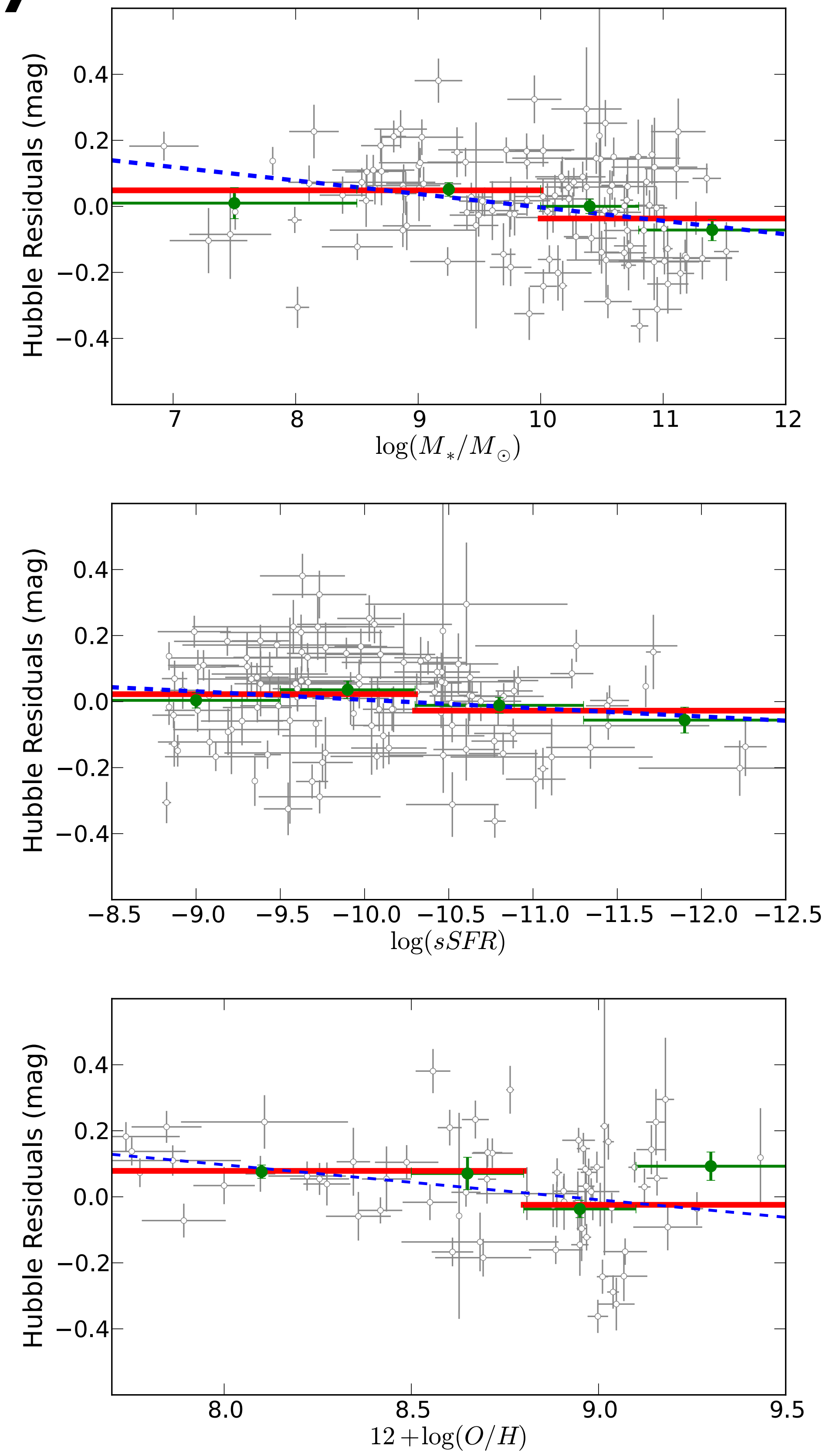
Uncertainty in SN Model Leads to Dark Energy Uncertainty

Kessler et al. (2009)



- Bulk of high-quality SN measurements in optical wavelengths and near peak
  - SNe less well understood in UV and NIR, well before and well after peak brightness
- Issue manifest in discrepancy of distances from different light-curve fitters
  - Inconsistent U-band templates
  - Different interpretation of color
  - Different priors

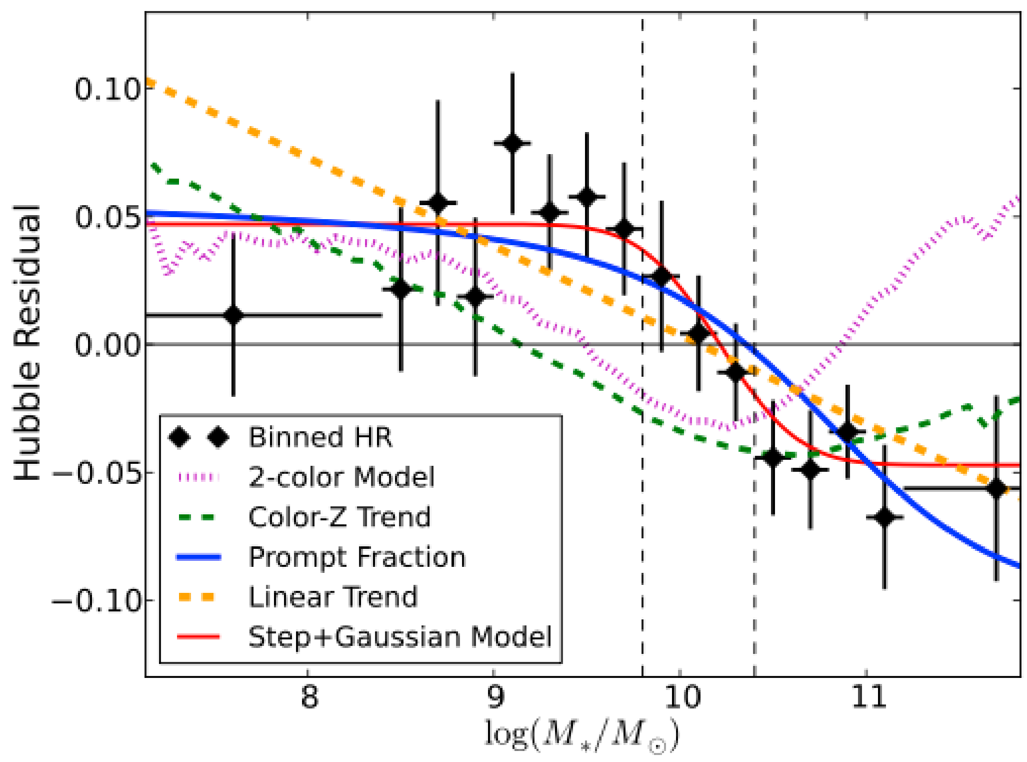
Uncertainty in SN Model Leads to Dark Energy Uncertainty

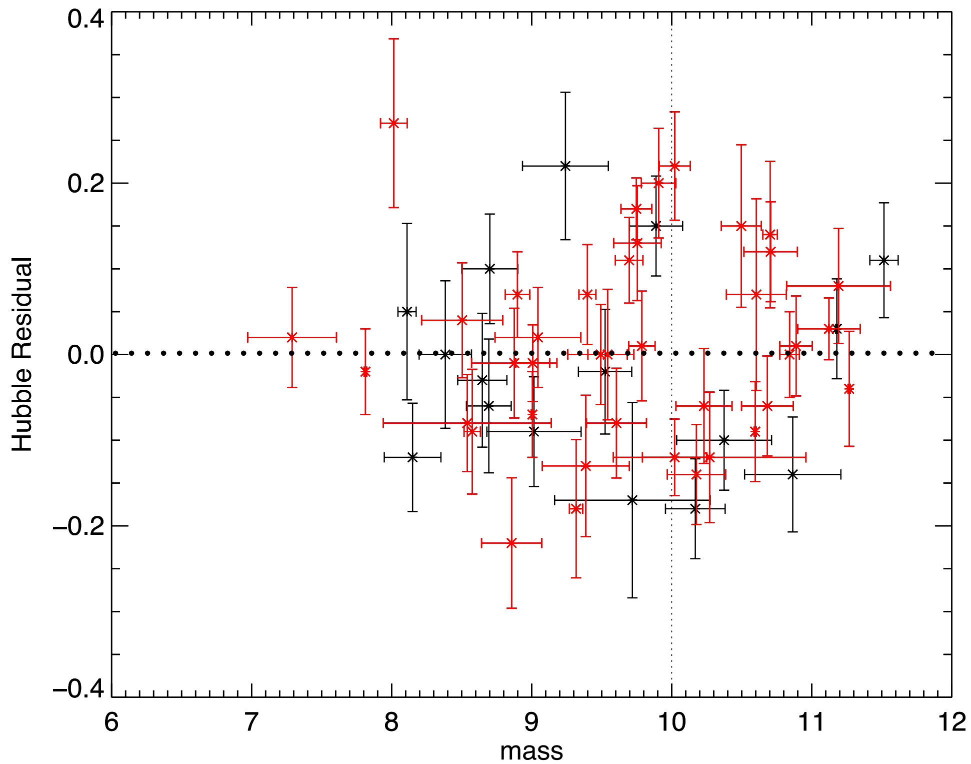


- Residuals in the supernova Hubble Diagram correlated with host-galaxy properties
- Supernova light-curve fitters do not fully capture supernova heterogeneity

New Supernova Parametrization Lowers Statistical and Systematic Uncertainties

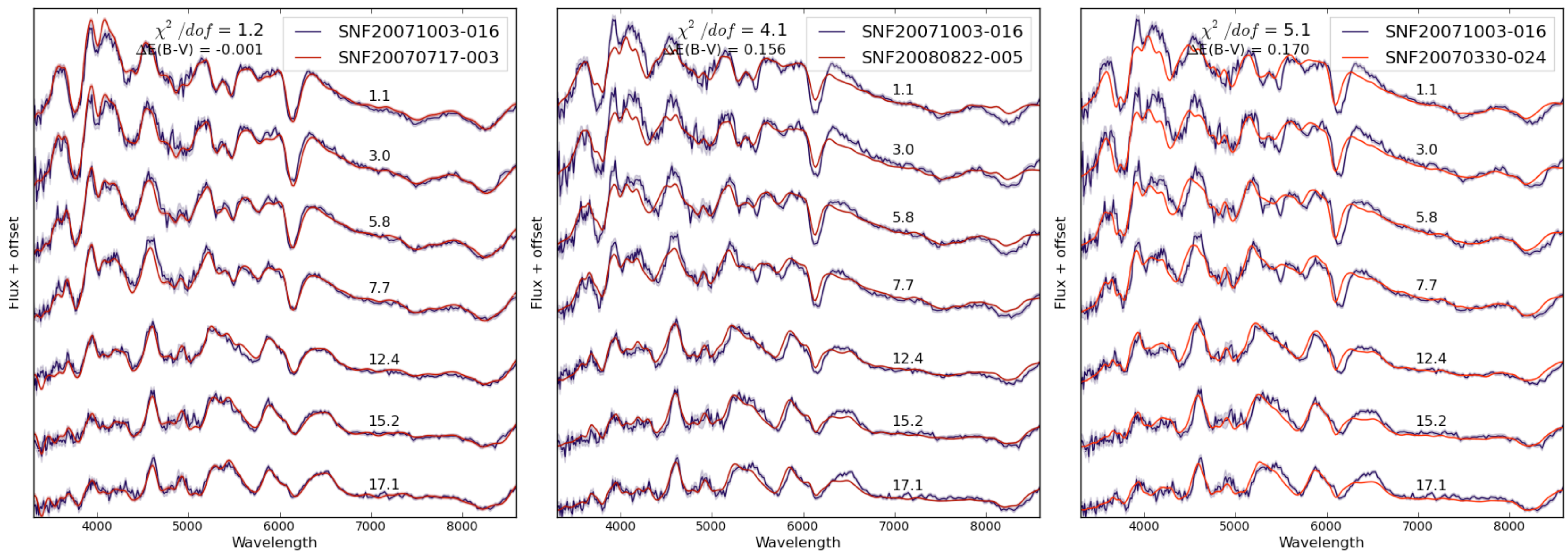
- Absolute magnitude dispersion of new method (0.107 mag) better than other methods also using optical data (0.15 mag), and as well using optical+NIR data (0.105 mag)
- Hubble residual step between low- and high-mass hosts disappears





New Supernova Parametrization Lowers Statistical and Systematic Uncertainties

- SNe Ia exhibit heterogeneity in their spectra
- Regress to put different SNe on a common time grid
- Compare similarity of spectral time series

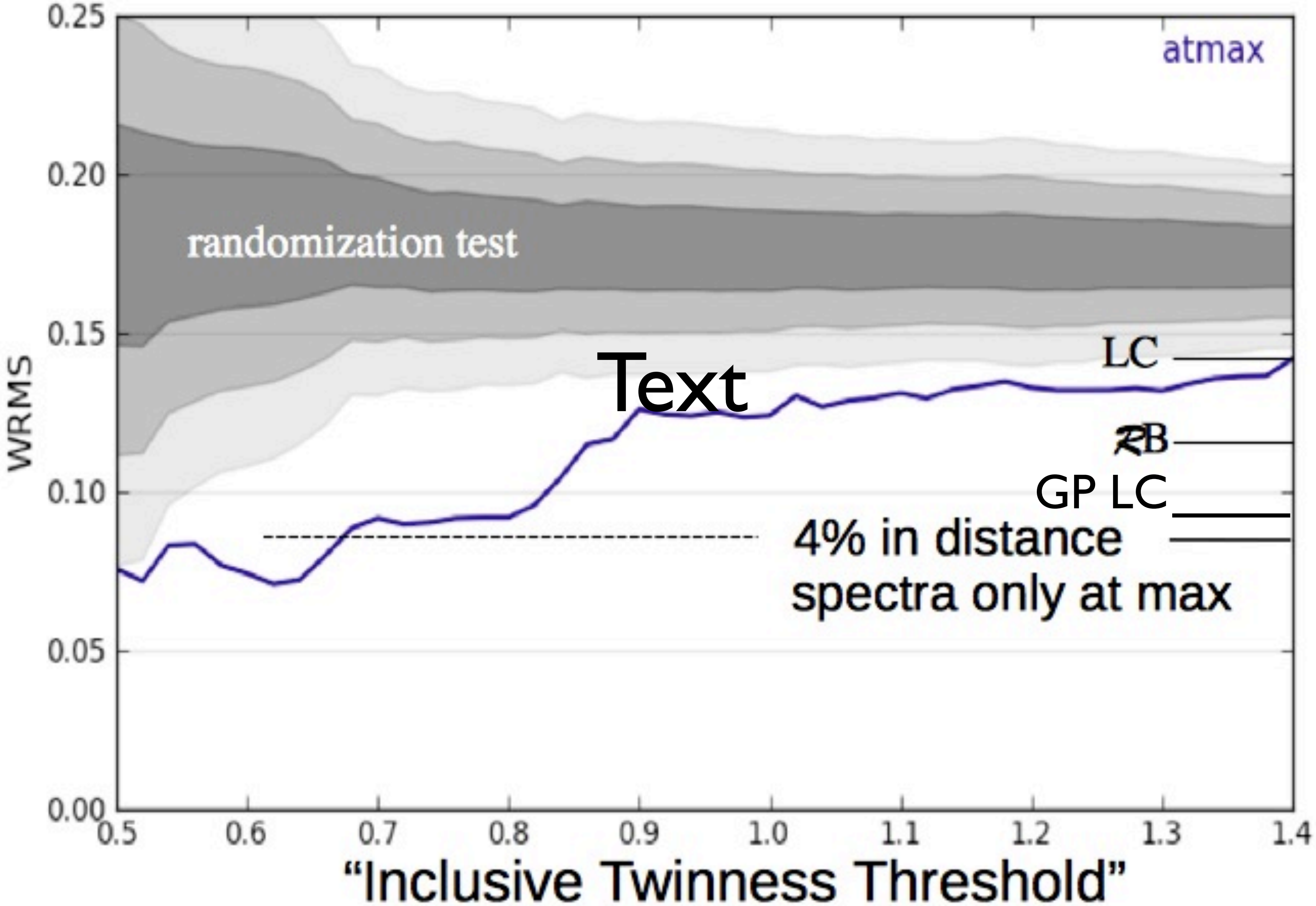


Twinny ⟷ Untwinny

- Expect twin supernovae to have the same luminosity

Improving the Determination of Supernova Luminosities Lowers Systematic Uncertainties

Precision
in determining
an individual
SN luminosity



- Better precision means less room for systematics to bite you

Reducing Calibration Uncertainty

- Absolute calibration
  - Current calibration is 2% (optical) to 3% (NIR)
  - ACCESS
    - On a rocket to get above the atmosphere
    - Fly NIST-calibrated photodiode detectors to calibrate a set of bright stars
    - <1% color calibration uncertainty
- Observatory calibration - planned for LSST
  - Star flats to calibrate relative PSF photometry at every position in the focal plane
  - Atmospheric monitoring and modeling
  - Tunable laser calibrates throughput of the telescope
- SNe are standard stars! Self-calibration

Photometry-Only Analysis

- "New" systematic: Active work on strategy to address this
- Redshift from host galaxy + SN photometric redshift inadequate for purposes of classification
    - Spectroscopic redshifts needed
    - No live-time requirement, can be done on host galaxy later
- Spectroscopic classification of an unbiased candidate subset
- DES an excellent testing ground for demonstrating the approach

Hans von Osten

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- Famous early 20th century mathematician
- Performed addition, subtraction, fractions, square roots
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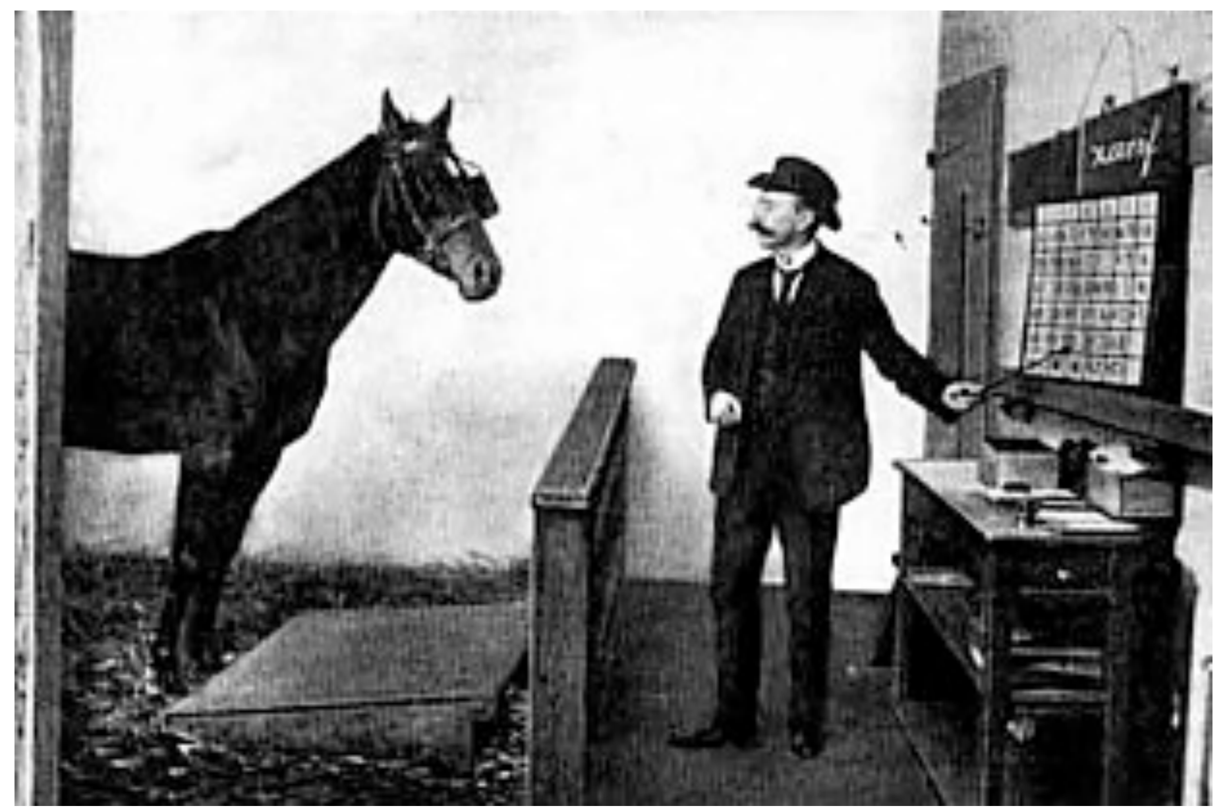
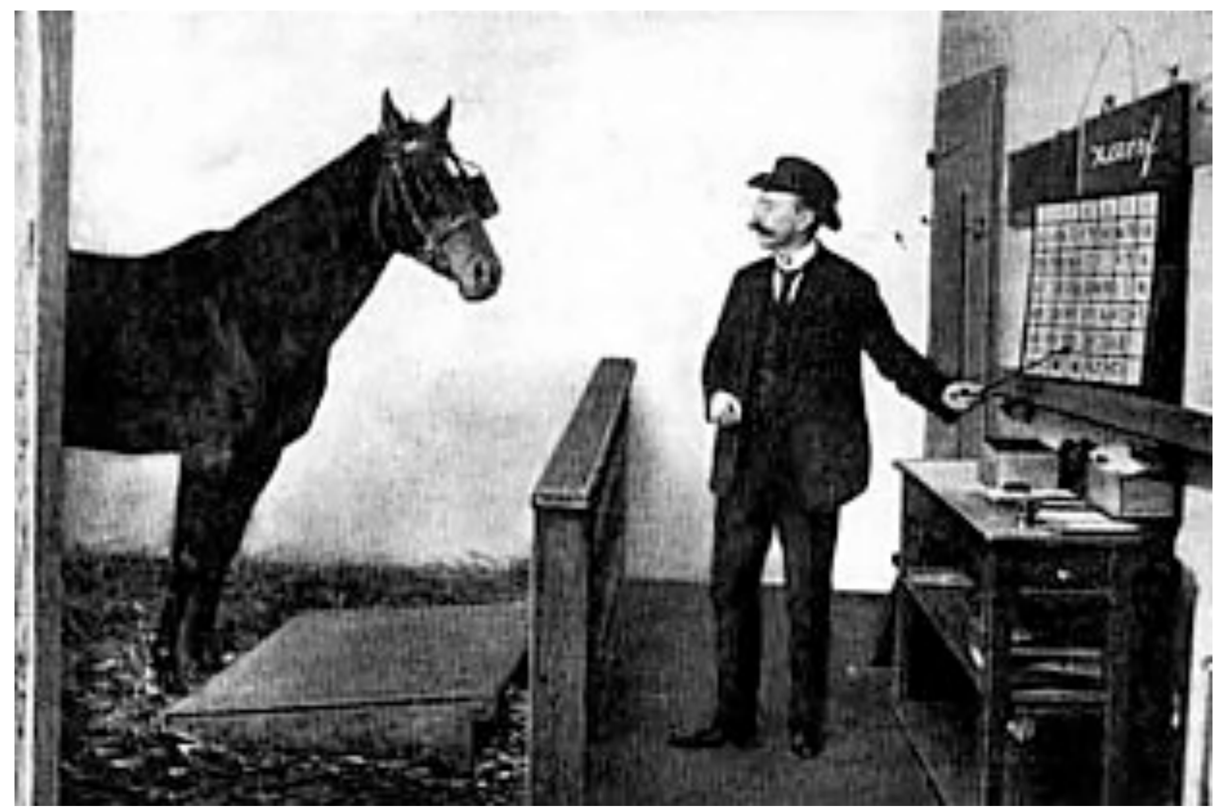


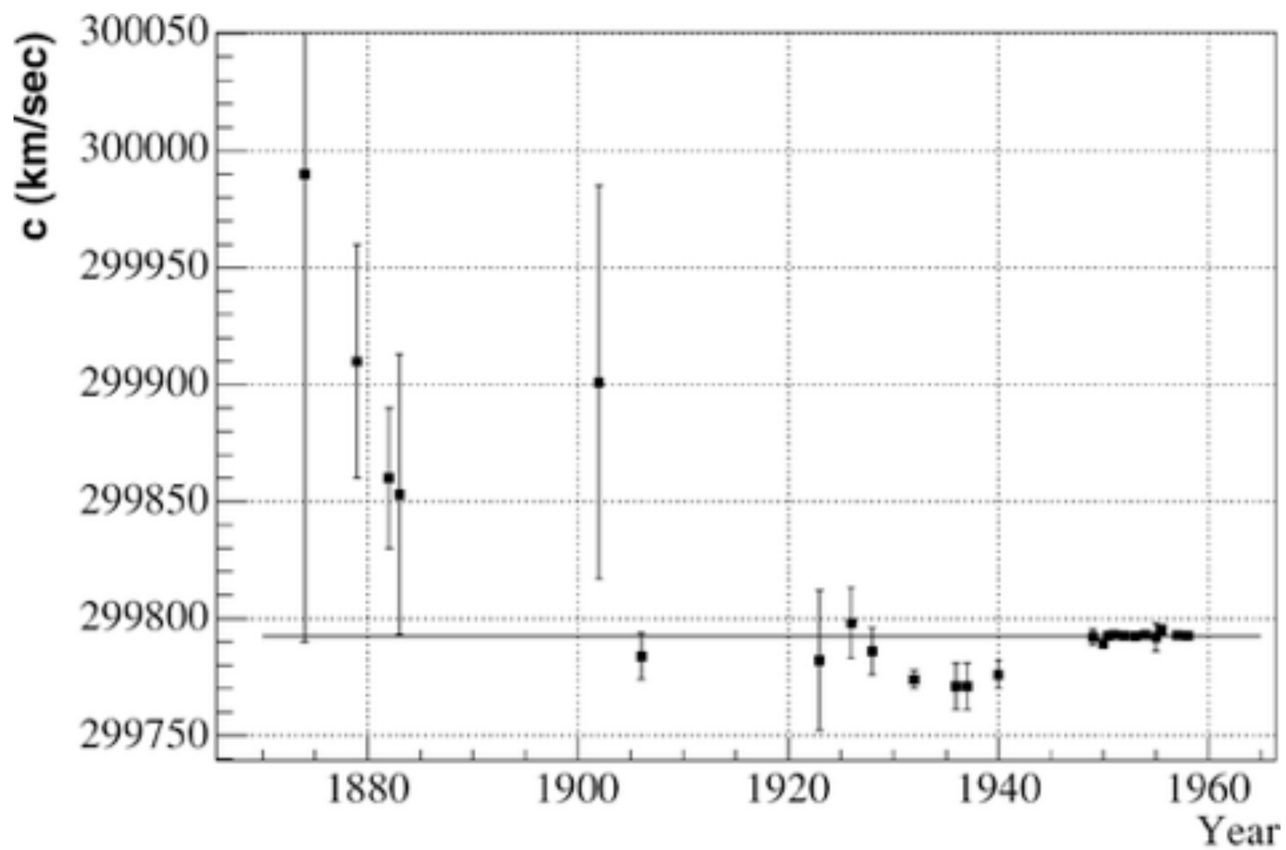
Hans von Osten

- Famous early 20th century mathematician
- Performed addition, subtraction, fractions, square roots
- Spelled German
- Investigation by the Prussian Minister of Education and the director of the Natural History Museum found no evidence of fraud



Clever Hans Explained

- Subsequent tests by Oskar Pfungst showed Hans performed poorly when the questioner didn't know the answer or if Hans couldn't see the questioner
- Hans was answering based on the involuntary reaction of human observers
- Hans gave the answer experimenters expected
- Experimenter bias can affect results



Klein JR. Roodman A. 2005.
Annu. Rev. Nucl. Part. Sci. 55:141–63

Blind Analysis: Reduces Scientist Bias

- Blind analysis is any method to hide some aspect of the data or result to prevent experimenter's bias
  - Dark energy parameters honing in on a Cosmological Constant - a special value preconceived to be good
- Blind analysis techniques for SN cosmology
  - Fit dark-energy values hidden during analysis
  - Hidden offset to magnitudes
  - Independent group decides when to unblind
  - Analysis procedure and selection criteria defined before data arrives
  - Unblinded analysis of a fraction of the data set
- Already used in some analyses

Conclusions

- As the tool used to discover the accelerating expansion of the universe and the leading probe of dark energy, the systematic error budget has been carefully scrutinized
- Current results are limited by systematic uncertainty
- There is a path forward to reduce current limiting systematics
  - Requires carefully planned low-redshift and cosmological surveys
  - Robust experimental design (space)
  - Advanced theoretical and empirical SN modeling